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Wireless Multimedia Sensor Network: A Survey on Multimedia Sensors

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***Abstract*—Recently due to progress in Complementary Metal Oxide Semiconductor (CMOS) technology, Wireless Multimedia Sensor Networks (WMSNs) become focus of research in a broader range of applications. In this survey paper different WMSNs applications, research & design challenges are outlined. In addition to this, different available commercial multimedia sensors are discussed in detail and compared. Also other then commercial available multimedia sensors, some experimental multimedia sensor prototypes are discussed. In addition to this different experimental deployed test beds for WMSNs are outlined. Also few Wireless Sensor Networks (WSNs) simulators and emulators are reviewed. Depending upon the requirement a few physical multimedia sensors can be integrated or embedded within available simulators to observe more accurate results or to visualize in a better way.**

***Index Terms*—wireless multimedia Sensor network, multimedia sensors, wireless sensor networks, review, survey, simulators, emulators.**

I. Introduction

Wireless multimedia sensor networks have drawn the attention of the researchers in the recent years. With the rapid improvements and progress in CMOS technology, camera and microphone have become integral part of wireless sensor node. Ref. [1, 2] WMSN is a wireless network of smart devices that allow retrieval of video and audio streams, still images and scalar data. Also WMSN can sense, store, process, communicate and fuse multimedia data from different heterogeneous sensor devices in real time environment as shown in Fig. 1. Realization of WMSN has emerged with diversity of application areas over traditional WSNs. Ref. [1, 2, 3] some important applications of WMSN are environmental monitoring & control, intelligent homes, health applications, traffic avoidance, enforcement & control, Industrial process control and multimedia surveillance.

The rest of the paper is organized as follows, in section 2 WMSNs constraints and design challenges are discussed. In section 3 different physical multimedia sensors are discussed. Section 4 provides brief overview of experimental WMSN test beds. In section 5 different WSN simulators and emulators are reviewed briefly. Finally last section conclude by summing up, figuring out the key issues and challenges for future research work.

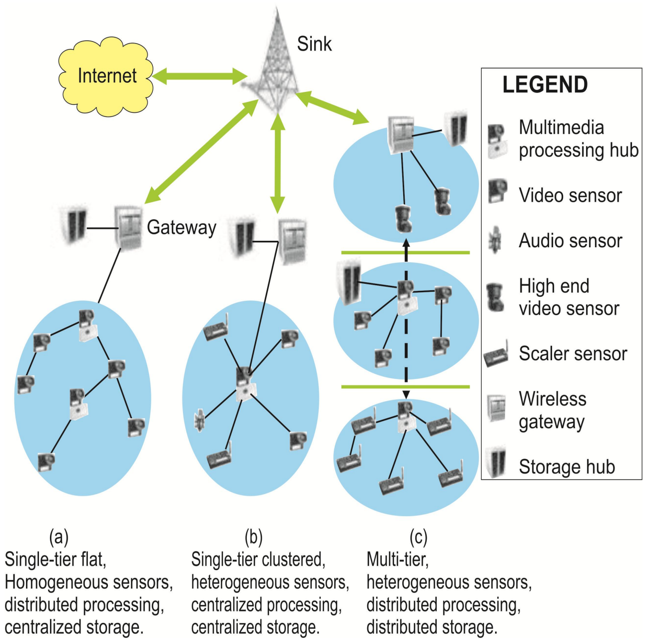

Figure 1. Reference Architecture of a WMSN

II. Design Challenges

The design of WMSNs includes research areas in embedded systems, signal processing and communications to make a more powerful and efficient network over traditional WSNs. These design challenges are

A. Resource Constraints

In comparison with WSNs, requirement of resources like battery power, memory, data rate, processing capability is more in WMSNs.

B. Multimedia Source Coding Techniquues

As the volume of multimedia traffic is very high efficient source coding techniques should be used for redundant data.

C. High Bandwidth Demands

Even after using source coding, Multimedia data stream requires higher bandwidth. This requires efficient new transmission methods and development of novel hardware architecture.

D. Energy Consumption

Energy consumption is of major concern in WMSN to guarantee QoS (Quality of Service) requirements.

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E. Application specific QoS Requirementss

Design of WMSN requires development of algorithms that supports QoS requirements which are specific to applications.

F. Multimedia In-Network Processings

Aggregation is possible with scalar data in WSNs. But it is not easy to apply the same techniques with WMSNs because multimedia information is carried in multiple packets of the stream. This becomes the challenge for future research work.

G. Cross layer Coupling of Functionalitiess

For energy efficient communication cross layer design is essential.

III. Multimedia Sensor Hardware

As compared to WSN a few multimedia sensors are available. In this section various commercial and experimental prototype multimedia sensor nodes are discussed and compared.

A. Cyclops

Ref. [4] as shown in Fig. 2, Cyclops consists of an image sensor, a micro-controller unit (MCU), a complex programmable logic device (CPLD), an external Static Random Access Memory (SRAM) and an external Flash Memory. Ref. [5, 6] Cyclops firmware runs in TinyOS operating system environment and is written in the nesC language. Its firmware provides transparency in using resources supports long computations and supports synchronized access by both the MCU as well as CPLD. Cyclops consist of three sets of software components namely drivers, libraries and sensor applications. Communication between MCU and peripherals is achieved using drivers. Primitive structural analysis libraries play a key role in processing raw images. Other class of library called high level algorithmic library used to do high level specific task. Sensor application performs sensing operation as per the requirement of host. Ref. [7] Cyclops can be interfaced with Micaz node for communication with other sensor nodes.

Figure 2. Cyclops Sensor Mote

B. CMUcam3

Ref. [8] the CMUcam3 as shown in Fig. 3, is a low cost, open source, fully programmable embedded vision sensor designed for simple vision tasks. Hardware architecture of CMUcam3 consists of three main components: microcontroller, a frame buffer and a CMOS camera chip. As CMUcam3 has only 64kB of RAM, Standard Vision Libraries cannot be used with this hardware. To address this CMUcam3 comes with its own software called CC3 software vision system which is a C Application programming Interface (API), performs vision and control operation for CMUcam3. Ref. [9] CMUcam3 can be interfaced with TelosB mote for communication with other sensor nodes. CMUcam3 is not applicable for complex vision algorithms as requirement of speed and Random Access Memory (RAM) is more. CMUcam3 can be used for low resolution video applications.

C. MeshEye

Ref. [10] MeshEye as shown in Fig. 4, is designed for in-node processing of applications in distributed intelligent surveillance. The objective of the MeshEye design architecture is combination of low-power components, readily available parts and use of standard interfaces with minimum count of total components. This aims to minimize the total cost. The core of mote is an Atmel family microcontroller. For wired connection it consists of a Universal Serial Bus (USB) 2.0 full-speed port and a serial interface. Wireless connection to other motes in the network can be established through a Texas Instruments CC2420 2.4 GHz IEEE 802.15.4/ZigBee-ready Radio Frequency (RF) transceiver. The mote can host up to 8K pixel imagers and one Video Graphics Array (VGA) camera module. For temporary frame buffering and image archival an MultiMediaCard/Secure Digital (MMC/SD) flash memory card is used. Like Cyclops, MeshEye can be used for low resolution video applications and with less cost factor.

Figure 3. CMUcam3

D. Panoptes

Ref. [11] as shown in Fig. 5, Panoptes is low power, High quality video capturing sensor platform implemented using off-the-shelf components. The whole unit of approximate size 7 inches long and 4 inches wide consumes approximately 5.5 watts of power with video of 320x240 resolutions at 18-20

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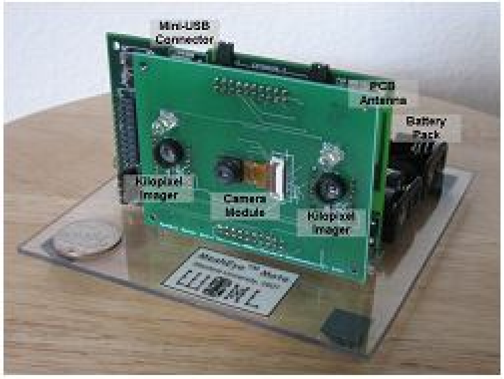

Figure 4. MeshEye Mote

fps. Panoptes is based on Intel StrongARM 206 MHz embedded platform, Logitech 3000 USB video camera, 64 MB of memory and 802.11 networking interface. Panoptes make use of Linux 2.4.19 operating system kernel. Its Software architecture consists of components like video capture, Filtering, Joint Photographic Experts Group (JPEG) and differential JPEG compression, buffering, adaption and streaming. Panoptes can be used in applications where higher resolution and image processing is required.

E. GARCIA

Ref. [12, 13] GARCIA is a mobile robot can be customized as per the requirement. This robot is the best choice for researchers who are looking to extend C, C++ or Java out into the real world via a reliable and robust robot platform. Currently GARCIA robot software downloads are available for MacOS, Linux and Windows. As shown in fig. 6, a camera boom with a pan-tilt head may be mounted on a Garcia as an optional accessory. This mounted tilt camera is able to communicate with IEEE 802.4 as well as Zigbee interfaces. GARCIA robot consist of automated motion control and obstacle detection system. A Garcia robot consists of two BrainStem controllers. These controllers

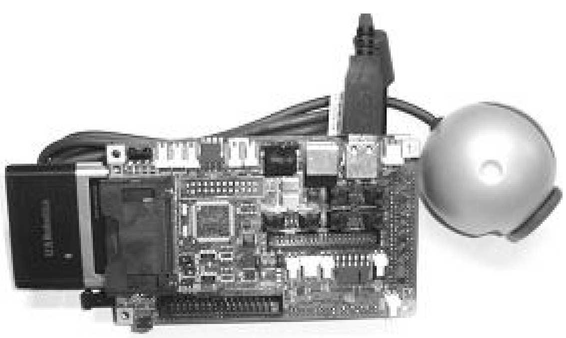

Figure 5. Penoptes Sensor

are programmable in Tiny Embedded Application (TEA) which is a subset of the C programming language. GARCIA mobile robots can be used in heterogeneous sensor network environment.

F. MicrelEye

Ref. [14] as shown in Fig. 7, MicrelEye is a low cost low power FPGA microcontroller System-on-Chip (SoC). This sensor node equipped with single solar cell and a battery.

Figure 6. Acroname GARCIA, a Mobile Robot

Battery is used as a backup when energy requirement with solar cell is not enough. It consists of lowest energy consumable ATMEL FPSLIC configurable platform-featuring an AVR microcontroller, 40K gate Field Programmable Gate array (FPGA), omnivision 7640 video sensor and bluetooth transceiver. MicrelEye is a prototype developed over previously discussed sensors. This is based on low power consumption while supporting people detection application at 15 fps at 320X240 resolution.

G. Fox board based sensor

Ref. [15, 16] as shown in Fig. 8, this board named LX416 is used for high quality image transmission using bluetooth with moderate energy consumption compared to other technologies. It consist of 4MB of Flash memory, 16 MB of RAM, 2 USB host interfaces to plug webcam and bluetooth dongle, 10/100 Ethernet interface. This experimental prototype was developed for environmental observations for multimedia data. Main goal of this prototype was high quality image transmission using Bluetooth.

Figure 7. MicrelEye Sensor Node Prototype

H. IMote2

Ref. [17, 18] as shown in Fig. 9, IMote2 is modular and stackable sensor node platform developed by Intel, designed for more advanced applications. The IMote2 contains low power Intel PXA271 Central Processing Unit (CPU) processor which consists of 256kB of SRAM, 32MB of flash, and 32MB of Synchronous Dynamic Random Access Memory (SDRAM). The PXA271 also includes a Digital Signal processing (DSP) coprocessor to speed up multimedia

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Figure 8. Acme Fox Board with Quickcam zoom webcam and Bluetooth Dongle

operations. This board integrates many I/O options making it extremely flexible in .supporting different sensors. IMote2 consist of a Power Management IC (PMIC) which supports 9 voltage domains to the processor, enabling wide range of applications. Imote2 uses IEEE 802.15.4 radio transceiver for communication with other nodes. It can run java applications and Linux operating systems. Imote2 can be used for variety of applications as compared to other sensor platforms.

All Multimedia sensors discussed before are compared with respect to Resolution, Transceiver availability for communication and Frame Rate in Table I.

IV. Experimental Wmsn Test Beds

Several experimental studies are carried out based on multimedia communications through wireless sensor networks. Following section highlights these test beds briefly.

Figure 9. IMote2 with Enalab Camera Board

A. Meerkats Test Bed

Ref. [19] Meerkats test bed focuses tradeoff between power efficiency and performance. It is used to measure the energy consumption for different types of applications for WMSN. These energy consumption categories are idle, Processing-intensive, Storage-intensive, Communication-intensive, visual sensing. Currently, Meerkats testbed consists of eight visual Sensor nodes and one information sink. Ref. [20] every sensor node use Crossbow's Stargates. As shown in Fig. 10, each Stargate is equipped with an Orinoco Gold 802.11b Personal Computer Memory Card

Table I. Comparison Of Multimedia Sensors

Name	Resolution	Transceiver Availability for communication	Max. Frame Rate in fps
Cyclop	352x288	No(can be integrated with Mica2 or Micaz)	NA
CMUcam3	352x288	No(can be integrated with TelosB)	50
MeshEye	352x288	Yes	15
Panoptes	320x240	Yes	20
GARCIA	640x480	Yes	30
MicrelEye	320x240	Yes	15
Fox based sensor	640x480	Yes	NA
Imote2	640x480	Yes	30

International Association (PCMCIA) wireless card and a Logitech QuickCam Pro 4000 webcam connected through the USB. Resolution of QuickCam is up to 640x480 pixels. The operating system used is an embedded Linux system (kernel 2.4.19). A Dell Inspiron 4000 laptop is used as the sink. It runs on Linux (kernel 2.4.20) and uses an Orinoco Gold 802.11b wireless card for communication. One important observation is that read/write operation to flash memory and image processing operation requires more energy compared to communication.

B. IrisNet

Ref. [21] IrisNet (Internet-scale Resource sensor Network services) is WMSNs heterogeneous services software platform developed by Intel research group.

Figure 10. Visual Sensing Node in Meerkats Test bed

Scalar and multimedia sensors collect useful data throughout environmental area. IrisNet is two tiered architecture: Sensing Agents (SA) are heterogeneous sensors having a common shared interface and organizing Agents (OA) stores distributed database. Same hardware infrastructure can provide different sensing services and can be used for different services simultaneously. Sensor data is organized hierarchical in the form of Extensible Markup Language (XML). IrisNet is a query based architecture. User can query through a high level language to get required useful information.

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C. SensEye

Ref. [22] as shown in Fig. 11, SensEye is a three-tier heterogeneous multimedia sensor network designed for surveillance application addresses the tradeoff issue of energy and reliability. Lowest first tier consist of motes and vibration sensors. This tier detects objects with the help of vibration sensors and communicates to the second tier which consists of low power low fidelity multimedia sensors (Cyclops, CMUcam3). These sensors from Tier-2 are used for motion detection and recognition. These low tier nodes detect object and wakeup tier-3 nodes. Tier-3 consists of medium-resolution webcams connected to Crossbow Stargate boards. Here nodes are preconfigured with image database to do object matching. After Object matching various web-cams and Pan-tilt-zoom cameras are used for object tracking in Tier-3. For object tracking handoff protocol is used to transfer responsibility from one camera sensor to another sensor.

V. Simulators And Emulators

Basically researchers make use of different simulators and emulators to test and compare their results. Currently there are many open source and commercial simulators and emulators are available for researchers. In this section, few observations are made on WSN simulators based on previous published surveys and review papers. Also several WSN emulators are discussed in brief.

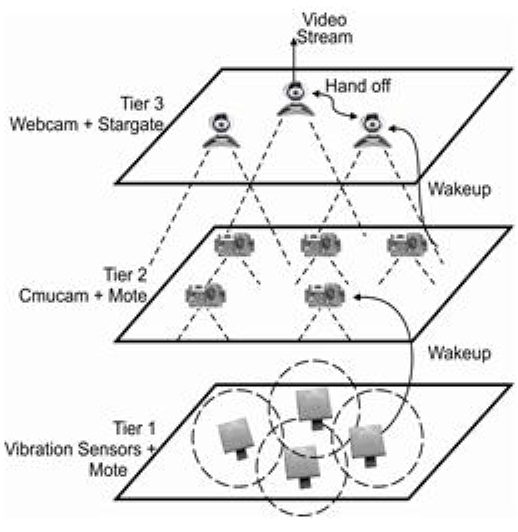

Figure 11. Three-Tier Architecture of SensEye

A. Simulators

Ref. [23, 24, 25] depending upon simulators characteristics and required available features, researchers should choose appropriate simulator. It is observed that common simulation scenario on different simulators gives mismatch of results may be within acceptable limits. Ref. [26, 27] generally used simulators for WSN provide very less information on environmental modeling. New challenging extensions or modifications in existing simulators are required to have more precise experimental results for the behavior of a complex system or application.

Ref. [28] network topologies and traffic models play an important role in working of WSN simulations. Study has been carried out to perceive the impact of multiple topologies and various traffic models on behavior and performance of simulation. This study shows that WSN simulators are very sensitive to network topology and network traffic configurations.

Ref. [29] this work is carried out to calibrate and compare four open source WSN simulators. This comparison study is based on antenna, topology, wireless channel, energy consumption and MAC layer. All these simulators are calibrated with Micaz motes. This comparison study shows that even after calibration, energy consumption and number of received packets by nodes differ extensively from each other.

B. Emulators

Ref. [30] ATmel EMUlator (ATEMU) is scalable and high fidelity platform provides low level emulation support for any operation at component level for the sensor nodes. Ref. [31] it provides support for Mica2 motes but can be extended for any other sensor hardware mote. It provides instruction level debugging feature. XML is used to configure the sensor network. ATEMU gives precise results at a cost of high processing requirements and time.

Ref. [32] EmStar is a software framework for WSN on Linux or windows based operating system which aims for development with high system visibility. It provides support for real wireless sensors to communicate with simulation environment. This work is carried out on two types of sensor arrays. First one is permanently mounted uniform array of motes on ceiling of laboratory which has limitations on topology and channel and other type is portable array. Instead of wireless communication here all sensor nodes are physically wired to simulator to observe the results.

Ref. [33] Avrora is instruction level emulator written in java, supporting up to 10,000 sensor nodes for simulation and 20 times faster than ATEMU. It provides features like cycle accuracy, portability and linear scalability. It focuses mainly on to validate time-dependent properties for large sensor networks.

Ref. [34] VMNet is a CPU clock cycle level emulator for realistic performance evaluation of WSN. In this other then CPU component, different hardware components are emulated as per satisfactory requirements. VMNet can be extended for new hardware mote configurations. This study shows use of response time and power consumption as the key performance metrics to match with actual WSNs. It is observed that there is a tradeoff between fidelity and emulation speed in VMNet.

Ref. [35] this work focuses on many hardware and software simulation modules or plug-in components developed for TinyOS-2 SIMulator (TOSSIM-T2) and compatible with Mica2 motes. This piece of work matches with actual physical laboratory measurements very closely only with two factors i.e., energy consumption and life time of nodes. Here other factors are not considered.

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Ref. [36] Sensor Unified aNalyzer for Software and Hardware in Networked Environments (SUNSHINE) is open source software designed for WSN to analyze joint software-hardware performance evaluation. It integrates three existing simulators i.e., TOSSIM, SimulAVR and GEZEL which provides support for both event-based and cycle-accurate simulations. Researcher can modify hardware sensor configurations in SUNSHINE. It can simulate impact of different hardware designs on sensor network.

Conclusions

In this paper various multimedia sensors are presented which are different from scalar sensors. Suitable multimedia sensors can be used depending upon the nature of the application.

Simulator and emulator tools are used to model and predict behavior of real sensor network environment at low cost and in lesser time. With the help of these tools researchers can test and debug various functionalities of related work to match with the expected one. Many available tools are designed for different features. Few studies on tools have shown that, a same scenario on different tools gives mismatch in the results. Even some studies shown that there is a large difference in accuracy for simulated results with the real one.

On the other hand deployment of physical test beds in real WMSN environment gives more accurate results. Deployment of real test bed even with 100 numbers of multimedia sensors or heterogeneous sensors involves a huge cost which is not affordable for researchers.

Most of these WSN simulator tools with extensibility support to develop new plug-ins can be used for WMSN research work. By taking this into consideration there is wide scope for research to integrate or to embed a physical multimedia sensor node into a virtual simulation process of simulator. This integration of physical node may give further improvement in accuracy and in overall performance of the expected results. Also to balance the cost factor this integration of physical multimedia sensor nodes can be limited to 1 to 4 in a virtual simulation process. Further to conclude, this paper will help research community to choose appropriate multimedia sensors and to explore different research challenges in the domain of WMSN.

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